EFFECTS OF THE TSUNAMI OF 26 DECEMBER 2004 ON RASDHOO AND NORTHERN ARI ATOLLS, MALDIVES

BY

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INTRODUCTION

We report our observations on Radhoo Atoll, located in the Maldives, during the tsunami of 26 December 2004. Observations were made on a marginal reef island and from a small boat in the lagoon of the atoll. Post-tsunami changes on some islands and reefs of Rasdhoo and nearby Ari Atoll are described.

SETTING

The Maldive archipelago is about 1,000 km long and up to 150 km wide encompassing an area of 107,500 km2 (Fig. 1). Some 0.3% of this area is formed by 1,200 islands, only 10 of which are larger than 2 km2. The maximum land elevation is 5 m above present sea-level. Geomorphologically, the Maldives form a N-S-trending double row of 22 atolls, separated by the Inner Sea up to 450 m deep. The Maldives are bounded bathymetrically by the 2,000 m contour, i.e., the archipelago rises steeply from the surrounding Indian Ocean seabed.

The geological development of the Maldives since the early Tertiary was recently summarized by Purdy and Bertram (1993) and Belopolsky and Droxler (2003). Whereas the knowledge of the Tertiary development is well documented based on ODP drill sites and exploration wells and seismics, the knowledge on the Quaternary evolution of the Maldives is quite limited (e.g., Woodroffe, 1992; Kench et al., 2005).

The climate is monsoon-dominated. During the wet monsoon from April to November winds blow to the NE, during the dry monsoon from December to March winds blow to the SW. Annually, most strongest and frequent winds blow towards the E (Fig. 1). Due to their proximity to the equator, the Maldives are largely storm-free. Water temperatures fluctuated annually between 28-30 °C during the past several years (COADS, grid 3-5°N, 72-74°E). Annual precipitation rates ranged from 1,000-2,000 mm during the 20th century (GHCN, Minicoy, Laccadives). The tidal range in the Maldives is 0.5-1 m.

Rasdhoo Atoll is located in the western row of Maldivian atolls. It is a comparably small atoll with a maximum diameter of 9.25 km and a size of 62 km^2 (Fig. 2). The marginal reef is near-continuous and surface breaking. There are 5 sand and

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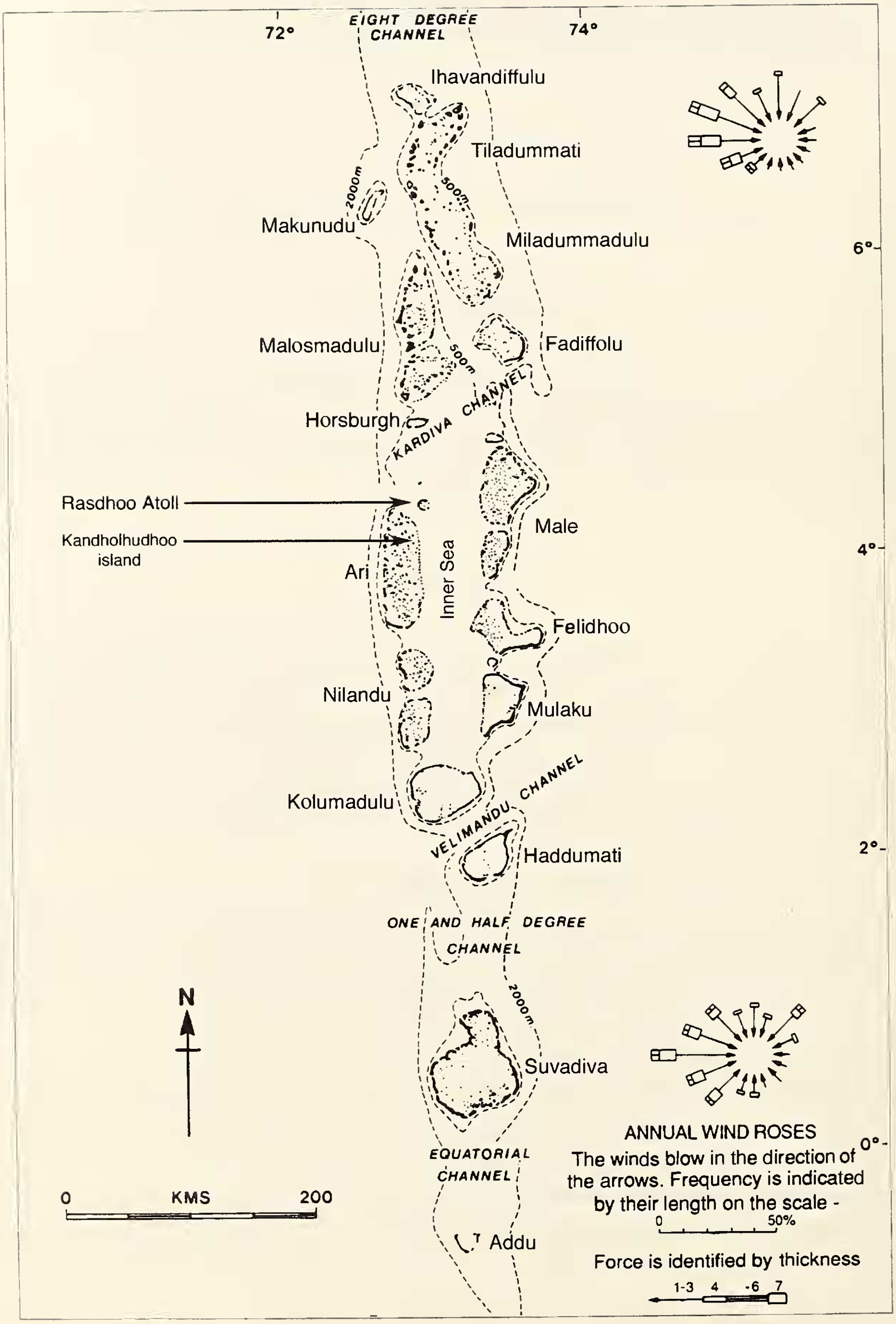

Figure 1. Map of the Maldive archipelago including wind data (after Purdy and Bertram, 1993). Upper arrow points to Rasdhoo Atoll. Lower arrow below points to location of Kandholhudhoo island where post-tsunami observations were made.

rubble islands on the marginal reef named Kuramathi, Rasdhoo, Madivaru, Madivaru Finolhu, and Veligandu, from west to east. Three channels through the marginal reef connect the interior lagoon with the open ocean and Inner Sea, respectively. The lagoon is up to 40 m deep and there are about 40 lagoonal coral patch reefs. Lagoonward of the peripheral reefs, a sand apron is developed, which is widest on the western side of the atoll. In the northern and western lagoon, an elongated ridge of coral and sand is developed, which separates a narrow, up to 10 m deep lagoonal part from the rest of the lagoon. The fore reef slope is very narrow except on the western side of the atoll. The slope ends in an almost vertical drop-off. Previous work at Rasdhoo Atoll includes the coral study of Scheer (1974) who reports 99 species of coral. Early researchers such as Gardiner (1903) and Agassiz (1903) did not visit Rasdhoo Atoll.

Ari Atoll belongs to the largest atolls of the Maldives (Fig. 1). It is 95 km long, 33 km wide at the widest point, and covers an area of 2,300 km^2. The marginal reef is discontinuous with some 40 major passes. The lagoon is as deep as 80 m. Numerous sand

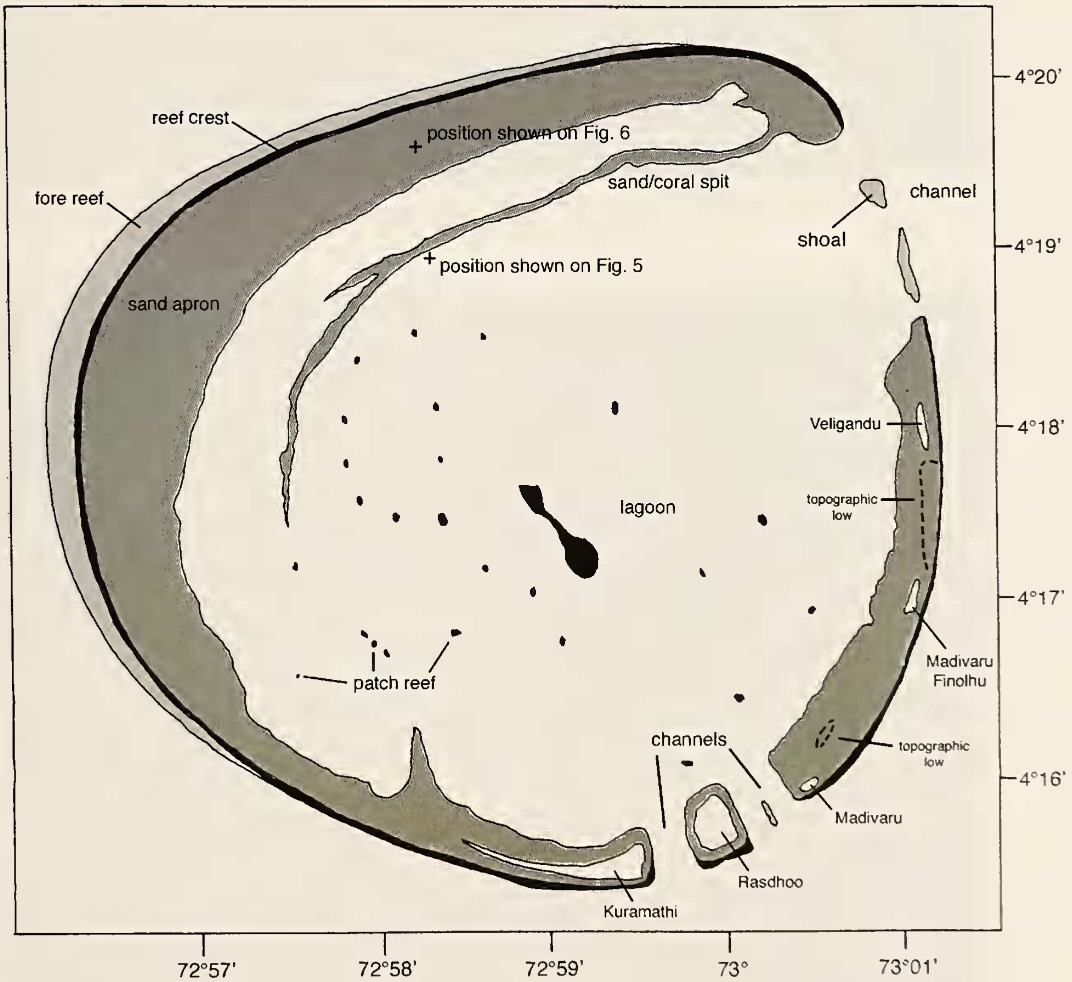

Figure 2. Map of Rasdhoo Atoll drawn from satellite image (from Gischler, 2006). Topographic lows in eastern reef are either locations of collapsed margin or former channels which are in the process of being filled in by sediment.

Figure 3. Nearly flooded sun deck in front of "Kuramathi Cottage" bar. 9:51 a.m., Rasdhoo Atoll.

Figure 4. Flooded path between "Kuramathi Cottage" restaurant and the lagoon. 9:50 a.m., Rasdhoo Atoll.

Figure 5. Lagoon of Rasdhoo Atoll at about 10 a.m. looking north. In the foreground, the long east-west-trending sand/coral spit is seen; water is "boiling" over the sand spit as a consequence of strong currents. The northern marginal reef of the atoll is seen in the background.

Figure 6. Northern margin of Rasdhoo lagoon at about 11 a.m. looking north. The marginal reef can be seen in the background, about 250 m in the distance. Note how lagoon water has turned "milky" as a consequence of fine sediment suspension.

and rubble islands on the marginal reefs and on lagoonal shoals make up 8.3 km2 (Naseer and Hatcher, 2004). Within the lagoon there are about 140 major patch reefs and faroes. Among the early researchers, Agassiz (1903, 103-107) visited Ari Atoll and made geomorphological observations.

CHRONOLOGY

On Sunday morning, 26 December 2004, one of us (R.K.) went to the beach of the atoll lagoon at the tourist resort "Kuramathi Cottage" on Kuramathi island, Rasdhoo Atoll. It was about 9:30 a.m., weather conditions were fine with blue sky and moderate wind from the ENE. Sea-level was unusually low at this moment and it was still falling fast. It even fell below the springtide minimum. For this day, however, the December tide table predicted low tide at 7:12 a.m., high tide at 12:29 p.m., with a tidal range of only 31 cm. After the initial low water, sea-level started to rise rapidly (Fig. 3). It was not a breaking wave coming in; it was merely rising water. At 9:50 a.m. the nearshore areas were already flooded, and the highest water level was reached by 9:53 a.m (Fig. 4). The water level ascended to the foundations of certain buildings, e.g., the Cottage diving school and the Cottage bar; then it started to fall fast. Within ten minutes it fell by two meters. Subsequent rising and falling of the ocean continued for about three hours, probably triggered additionally by seiche-type standing waves inside the atoll lagoon. The amplitude sea-level oscillations decreased with time, and at 1:00 p.m. the level was once again stable.

The other one of us (E.G.) had rented a local boat (dhoni) at the tourist resort "Kuramathi Village" at the E end of Kuramathi island on the morning of 26 December in order to collect surface sediment samples from Rasdhoo Atoll lagoon. After an hour of sampling, around 10 a.m., the dhoni had reached the E-W-trending sand/coral spit, which separates the atoll lagoon in the north. The boat captain was just trying to cross the spit between several coral heads when sea- level fell dramatically so that coral heads were subaerially exposed. It was not possible to measure the fall due to the lack of a reference point, however, sea-level fell by at least 1 m. The water rose again quickly and strong currents caused the water on top of the spit to "boil" (Fig. 5). We were discussing what could have caused this rapid sea-level fluctuation, but nobody on the boat realized what had really happened. We surrounded the sand/coral spit in the west and continued to collect sediment samples to the north of the spit. In order to get samples from the marginal back reef sand apron, E.G. had to swim towards the northern reef (Fig. 6). This task turned out as being very difficult. First, the visibility had meanwhile turned to almost zero because of the intensive sediment suspension. Second, the current direction was frequently changing, presumably due to seiche-type waves that had developed inside the lagoon. For these reasons it was almost impossible to remain on a straight course. We continued sampling, but when we tried to work in the NE channel in the early afternoon we had to stop because of up to 4 m high waves and swells coming into the lagoon. We eventually completed sampling in the eastern lagoon by 3:30 p.m. and returned to Kuramathi. Only then did we learn what had really happened in the morning. The sediment samples we collected are analyzed meanwhile, and the results are published elsewhere (Gischler, 2006).

EFFECTS ON THE ISLAND

No one was killed or injured on the island of Kuramathi. Some divers and snorkelers had difficulties due to strong currents and poor visibility, but everybody returned safely. There was minor damage of the infrastructure, including some water in three bungalows. The salt-tolerant vegetation along the supralitoral fringe, including the succulent salt bush (*Scaevola* sp.), the screw pine (*Pandanus* sp.), and the coconut trees (*Cocos nucifera*) did not suffer from the flooding. In contrast, flooded breadfruit trees (*Artocarpus* sp.) shed their leaves, but most of them recovered within weeks or months. Parts of the sandy beaches were eroded by the extreme high water, and soil from the island was washed into the atoll lagoon. The long sand bank at the west end of Kuramathi was practically cut in two by the tsunami (Fig. 7). Several hundred m^3 of sand were probably moved when a 10 m wide channel was cut in the sand spit. For months the beaches were constantly polluted by drifting debris washed ashore. The greatest commercial damage was done to the island by the subsequent holiday cancelling by many tourists.

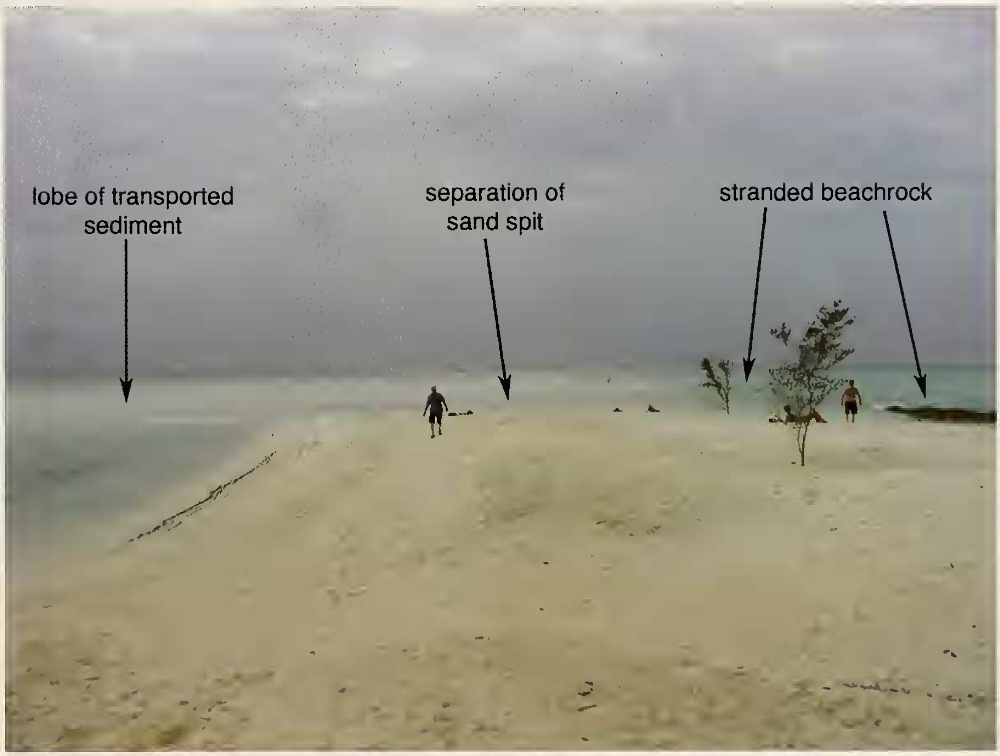

Figure 7. Sand bank at western end of Kuramathi island looking west. Sand bank was separated in two due to the tsunami. Note stranded beachrock at the northern (right) side of picture.

EFFECTS ON THE CORAL REEFS

There were two main stresses for the corals: sedimentation and mechanical stress. The strong water movement created massive sedimentation in the entire reef. Snorkelling one day after the tsunami showed a sediment-loaded reef. Within a few days, however, the reef made a cleaner impression. Most of the sediment was probably washed or actively transported away by the corals from their living surface. The number of broken corals was low. One reason might be the coral species composition after the 1998 bleaching event. During this natural disaster the fragile, fast-growing branched Acroporidae were dramatically reduced in number. At the time of the tsunami, massive-growing corals like Poritidae and Faviidae were dominant. Most of them were able to resist the strong swell.

The situation was different in the atoll channels. Extremely strong currents developed there, which equalized the changing water levels inside and outside the lagoon. Big coral boulders were knocked over by the surge, and a number of the strong *Tubastrea micrantha* corals were broken.

The tsunami had again a different impact on the coral reef around the small island Kandholhudhoo in the northern lagoon of Ari Atoll (04°00,118'N, 72°52,926'E; Fig. 1). The species composition of the Kandholhudhoo reef is remarkable, because it has a high percentage of branched and plate-like Acroporidae. They are mainly growing on unstable coral rubble. Therefore, many plate-like corals were knocked over together with their substrate, and they are in a tilted position now (Figs. 8, 9). Subsequent re-orientation of the tilted corals by special growth patterns of their marginal regions can be observed. A number of branched corals were also knocked over, or parts of the colonies broke away. At one position, in front of a channel, loads of sediment and coral rubble buried the upper part of the reef slope (Fig. 10). Secondary reef damage occurred months after the tsunami, when drifting tree-trunks floated by the Maldives. Those which were swept into shallow reefs broke the corals, and it was difficult to remove the trunks.

Figure 8. Kandholhudhoo (Ari Atoll), 3 m depth, 20 January 2005. The tsunami swell knocked over this table coral together with its substrate into an upside down position.

Figure 9. Kandholhudhoo (Ari Atoll), 3 m depth, 20 January 2005. Damselfishes (Pomacentridae) seek shelter between the branches of a tsunami-displaced *Acropora*.

Figure 10. Kandholhudhoo (Ari Atoll), tsunami triggered coral rubble slide down the reef slope. Depth 7 m, 20 January 2005.

SUMMARY

Due to the steep rise of the Maldives from the Indian Ocean sea bed, a considerable amount of energy of the December 2004 tsunami was apparently reflected and prohibited the building of a very high wave, thereby sparing the Maldives a similar catastrophe as, e.g., Sri Lanka or Sumatra. The islands on the eastern atoll chain were most heavily affected. Kuramathi and the other islands in Rasdhoo Atoll (Rasdhoo, Madivaru, Veligandu) were only minimally affected by the December 2004 tsunami, presumably due to the location of Rasdhoo in the western atoll chain and the fact that the marginal reef is almost continuous. The damage to the reefs was related to their exposition, topography, and species composition. In general, the reef damage was not heavy in this area. Diving in northern Ari Atoll showed a similar picture as in Rasdhoo Atoll. The 1998 bleaching event was much more devastating for the reefs in this region than the December 2004 tsunami.

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